

## Pupil Plane Filtering for Optical Pickup Heads with Effective Numerical Aperture of 1.1 and 2.0

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A pupil plane filtering technique is applied to data signal detection in an optical data storage system that uses a solid immersion lens (SIL) and a quadrilayer phase change recording medium. Two systems that have the effective numerical aperture ( $NA_{\text{EFF}}$ ) of 1.1 and 2.0 are investigated. A new filter is designed for the  $NA_{\text{EFF}} = 2.0$  system on the basis of this study. We have confirmed by numerical calculations that the technique improves signal contrast, which is defined by the ratio of the difference signal to the sum signal between the homogeneous crystalline area and the homogeneous amorphous area. We have also confirmed that the technique makes the contrast less sensitive to the gap width between the SIL and the recording medium. The vectorial feature of the light is considered in the calculations. The calculated irradiance distributions and signal levels for the system with  $NA_{\text{EFF}} = 1.1$  are confirmed by experiments.

KEYWORDS: optical data storage, signal contrast, filtering, solid immersion lens, near-field optics, phase-change medium

### 1. Introduction

Solid immersion lens (SIL) technology is a promising way to increase the data density of an optical storage system by decreasing the spot size. In a system using a hemispherical or hyperhemispherical SIL between an conventional objective lens and the recording medium, the optical spot diameter in the recording medium is reduced by a factor equal to the refractive index  $n_{\text{SIL}}$  or the square of it. The advantages of SIL systems have been demonstrated in many systems such as magneto-optical recording systems,<sup>1,2)</sup> a mastering system<sup>3)</sup> and phase-change recording systems.<sup>4,5)</sup>

However, in SIL systems, quality of the reproduced signal strictly depends on a gap width between the bottom surface of the SIL and the top surface of the medium. Gaps of only 100 nm can easily degrade the reproduced signal to unusable levels.<sup>6,7)</sup>

We find that the primary signal-degradation mechanism for small gap variation is the change in signal contrast and not the spot size. We have investigated the optical spot sizes and signal contrasts for a particular phase-change medium for several conditions.<sup>6,7)</sup> The signal contrast is defined as  $V = (i_X - i_A)/(i_X + i_A)$ , where  $i_X$  is the maximum detector signal corresponding to the crystalline area and  $i_A$  is the minimum detector signal corresponding to the amorphous area. With certain media structures and gap widths, the signal contrast can become close to zero due to a cancellation of positive and negative signal contributions distributed in the pupil of the objective lens.

We propose applying pupil plane filtering<sup>8)</sup> for reducing the cancellation and making the contrast less sensitive to the gap width. In this paper, two systems that have the effective numerical aperture ( $NA_{\text{EFF}}$ ) of 1.1 and 2.0 are investigated. First, the irradiance distributions of the light reflected by the recording medium at the pupil of the objective lens are calculated for both the crystalline and amorphous areas on the medium. The vectorial nature of the light is considered. Then, the signal contrasts with a filter and without a filter are cal-

culated. Results show that the contrast is improved and its sensitivity to gap-width variation is decreased by the filtering. The irradiance distributions and signal contrast for the  $NA_{\text{EFF}} = 1.1$  system are also confirmed experimentally.

### 2. Optics and Recording Medium

The optics assumed in this paper are shown in Fig. 1. Light from the laser diode is collimated and focused onto the recording medium by the objective lens and the hemispherical SIL. The light incident on the objective lens is linearly polarized in the  $x$  direction and  $\lambda = 650$  nm. The incident light is Gaussian shaped, and the ratio of the aperture of the objective lens to the beam size is 0.68. The numerical aperture of the objective lens is 0.6. Both glass and GaP SIL systems are considered. The refractive indexes ( $n_{\text{SIL}}$ ) of the SILs are 1.843 (LaSFN9) and 3.3 (GaP), and the effective numerical apertures ( $NA_{\text{EFF}}$ ) of the SIL systems are 1.1 and 2.0, respectively. The light reflected by the medium is collected by the SIL and the objective lens and directed to the photo detector.

An optical filter, which has a certain transmittance distribution, is introduced at the pupil plane after reflection from the recording layers. To realize the pupil plane filtering without disturbing the optical path from the light source to the recording medium, a 4- $f$  (focal length) imaging system is used. The optical filter is located on the plane where the image of the

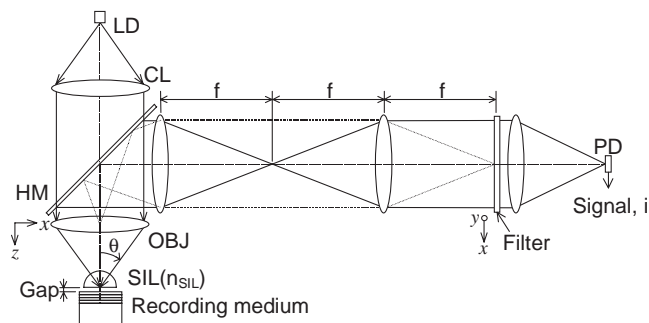


Fig. 1. Configuration of the optics with a hemisphere solid immersion lens (SIL) for pupil plane filtering. LD: Laser diode, CL: Collimator, HM: Half mirror, OBJ: Objective lens, SIL: Solid immersion lens, PD: Photo detector.

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